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BETON

BOLOMEYS OG NEPPERS FORMLER

INSTITUTTET FOR BYGNINGSTEKNIK

INSTITUTE OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING

AALBORG UNIVERSITETSCENTER • AUC • AALBORG • DANMARK

BETON

BOLOMEYS OG NEPPERS FORMLER

JENS KR. JEHRBO JENSEN

BETON: BOLOMEYS OG NEPPERS FORMLER

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FORORD

I denne rapport er Bolomeys og Neppers formler bearbejdet med henblik på at lette beregningerne af betonstyrker, når forholdene afviger fra det normale. Rapporten omfatter dels diagrammer, dels eksempler på anvendelse af disse.

INDLEDNING

Efter DS 411 skal styrkeprøvning af beton ske efter 28 døgn. Denne frist bliver af forskellige grunde ofte ikke overholdt, og da man herudover kan få lavet forkerte blandinger (f.eks. ændringer i cementtype og $\frac{V}{C}$ -tal), er der behov for at kunne beregne styrken af den faktisk fremstillede beton. Til dette formål anvendes Neppers formel, og i det følgende er denne formel sammen med Bolomeys formel brugt som grundlag for en række diagrammer, som kan lette beregningerne.

FORMLER

Bolomeys formel lyder

$$E(f_c) = K \left(\frac{1}{\sqrt{V/C}} - 0,50 \right) \quad (1)$$

hvor $E(f_c)$ er middelstyrken efter 28 døgn ved 20°C i $\text{MN} \cdot \text{m}^{-2}$

K er konstant = 27 $\text{MN} \cdot \text{m}^{-2}$ for PFC

og = 29 $\text{MN} \cdot \text{m}^{-2}$ for PC

V/C er vand-cementforholdet

Formlen gælder for $0,8 < \frac{V}{C} < 2,2$.

Neppers formel lyder

$$\ln E(f_c) = A_1 \cdot \frac{1}{\sqrt{t}} + A_2 \cdot \frac{V}{C} + A_3 \cdot \frac{1}{\sqrt{t}} \cdot \frac{V}{C} + A_4 \quad (2)$$

hvor t er modenhedsalderen i døgn ved 20°C

V/C er vand-cementforholdet

A 'erne er konstanter angivet i tabel 1.

| Cementtype | A_1 | A_2 | A_3 | A_4 |
|------------|-------|-------|-------|-------|
| PFC | -0,7 | -1,8 | -1,4 | +4,8 |
| PC | -0,5 | -1,8 | -1,0 | +4,8 |

Tabel 1. A -værdier i Neppers formel.

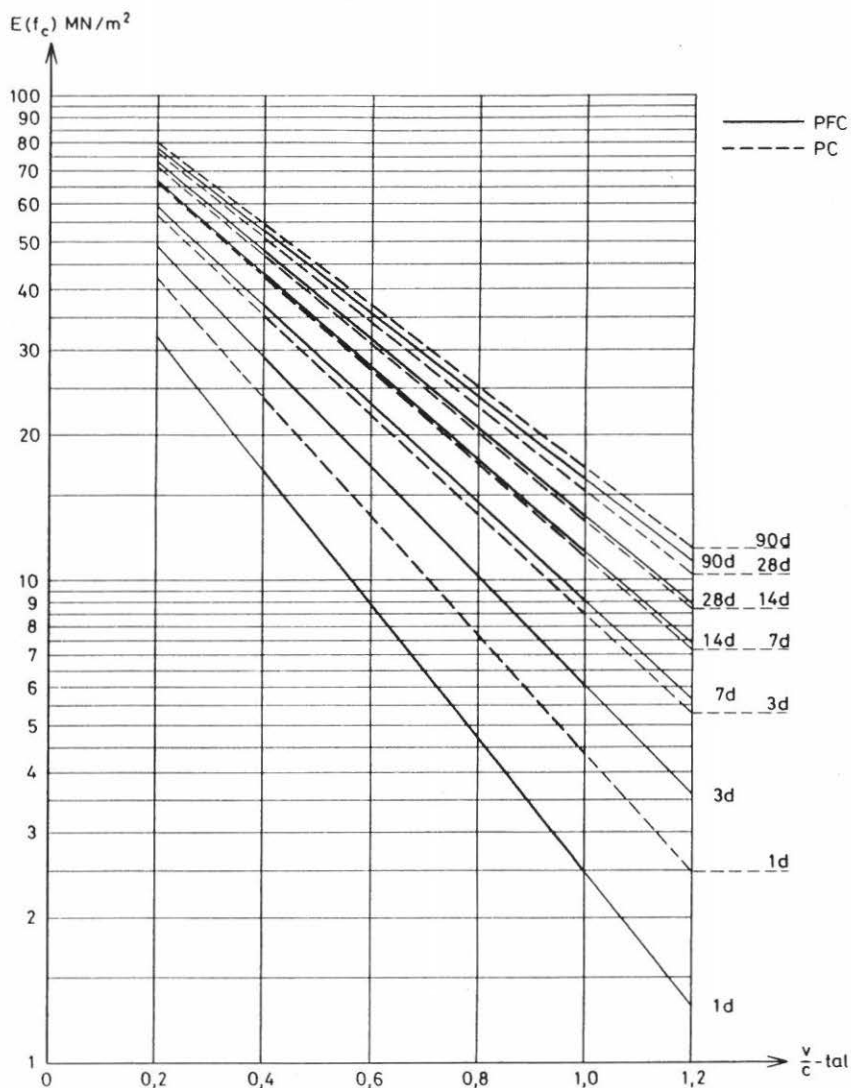
Neppers formel gælder i intervallet

$$0,4 \leq \frac{V}{C} \leq 1,0 \text{ og } 1 \text{ døgn} \leq t \leq 90 \text{ døgn}$$

Formlen er afbildet i figur 1 for de to cementtyper.

NEPPERS FORMEL

$$\ln E(f_c) = A_1 \frac{1}{\sqrt{f_c}} + A_2 \frac{v}{c} + A_3 \frac{1}{\sqrt{f_c}} \cdot \frac{v}{c} + A_4$$



Figur 1. Neppers formel for PFC og PC.

Modenhed

Ofte sker lagringen ikke ved konstant temperatur = 20°C. Det betyder, at modenheden ved 20°C skal beregnes i overensstemmelse med teorien for styrkeudviklingens temperaturafhængighed. Hvis hærdningshastigheden ved 20°C sættes til 1, vil hærdningshastigheden H ved temperatur T°C være givet ved

$$H = \exp \left[\frac{E}{8,314} \left(\frac{1}{293} - \frac{1}{273 + T} \right) \right]$$

$$\text{hvor } E = \begin{cases} 33500 + 1470 (20 - T) \text{ J} \cdot \text{mol}^{-1} & \text{for } T < 20^\circ \text{C} \\ 33500 \text{ J} \cdot \text{mol}^{-1} & \text{for } T \geq 20^\circ \text{C} \end{cases}$$

Tabel 2 viser værdien af H for udvalgte værdier af T.

| T°C | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 40 | 50 |
|-----|------|------|------|------|------|------|------|------|------|
| H | 0,15 | 0,29 | 0,50 | 0,75 | 1,00 | 1,26 | 1,57 | 2,41 | 3,59 |

Tabel 2. Hærdningshastigheder.

Modenheden ved 20°C udregnes som produktsummen af hærdningshastigheden og det antal døgn, hvor temperaturen har været konstant.

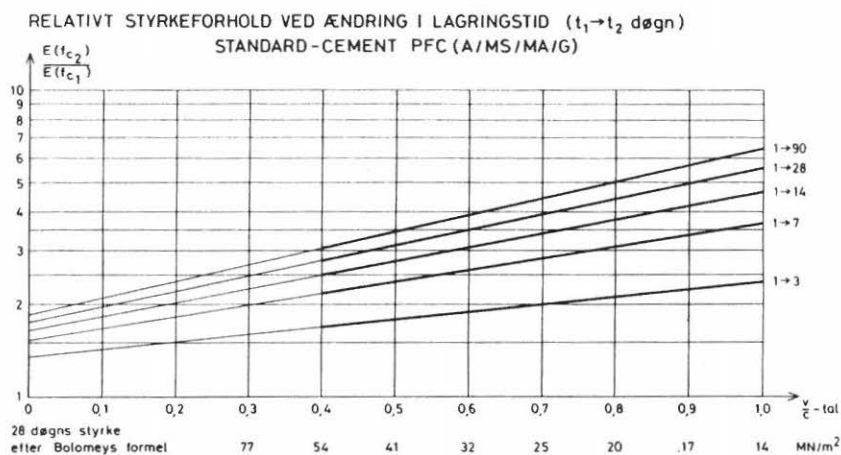
ANVENDELSER

Ændret lagringstid

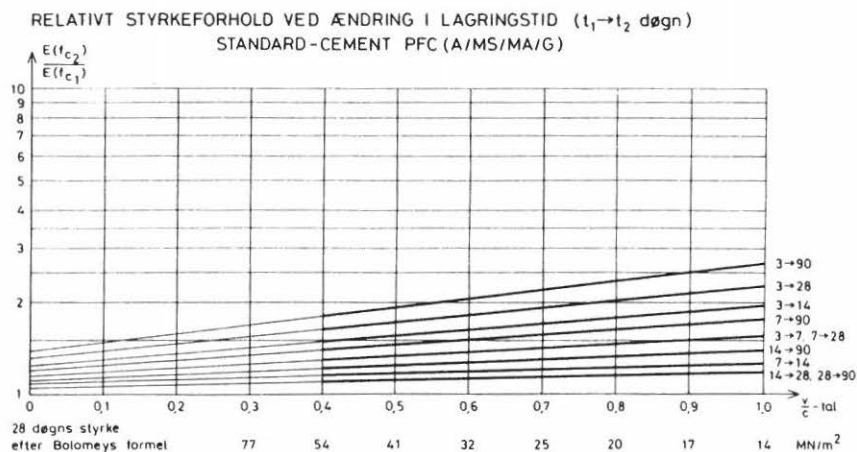
I mange tilfælde er man interesseret i at kunne beregne styrken ved en ændring i lagringstiden. Betragtes en beton med et givet $\frac{V}{C}$ -tal på to tidspunkter t_1 og t_2 fås følgende udtryk for styrkeforholdet

$$\ln \frac{E(f_{c2})}{E(f_{c1})} = \frac{\sqrt{t_1} - \sqrt{t_2}}{\sqrt{t_1} \cdot t_2} \cdot (A_1 + A_3 \cdot \frac{V}{C}) \quad (3)$$

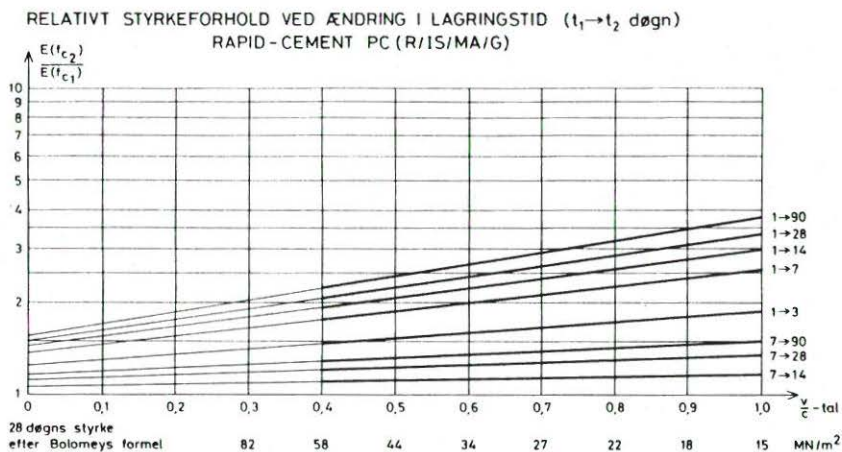
Denne formel er afbildet i figur 2 og 3 for PFC og figur 4 og 5 for PC. På alle 4 figurer er anført den 28 døgns styrke, man vil opnå efter Bolomeys formel (1). Der er valgt en række kombinationer af t_1 og t_2 , men i øvrigt kan formel (3) anvendes ved andre (t_1 og t_2)-værdier.



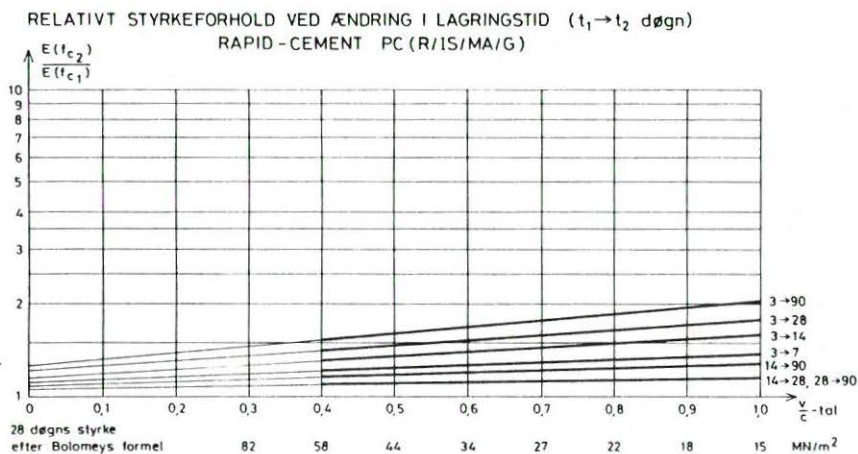
Figur 2. Ændret lagringstid (PFC).



Figur 3. Ændret lagringstid (PFC).



Figur 4. Ændret lagringstid (PC).



Figur 5. Ændret lagringstid (PC).

Ændret cementtype

Hvis man har lavet sin beton med en anden cementtype end antaget, vil styrkeforholdet til en given prøvningstermin ved overgang fra PFC til PC være givet ved

$$\ln \frac{E(f_c^{PC})}{E(f_c^{PFC})} = \frac{1}{\sqrt{t}} \cdot (\Delta A_1 + \Delta A_3 \cdot \frac{V}{C}) \quad (4)$$

hvor $\Delta A_1 = A_1 (PC) - A_1 (PFC) = 0,2$

$\Delta A_3 = A_3 (PC) - A_3 (PFC) = 0,4$

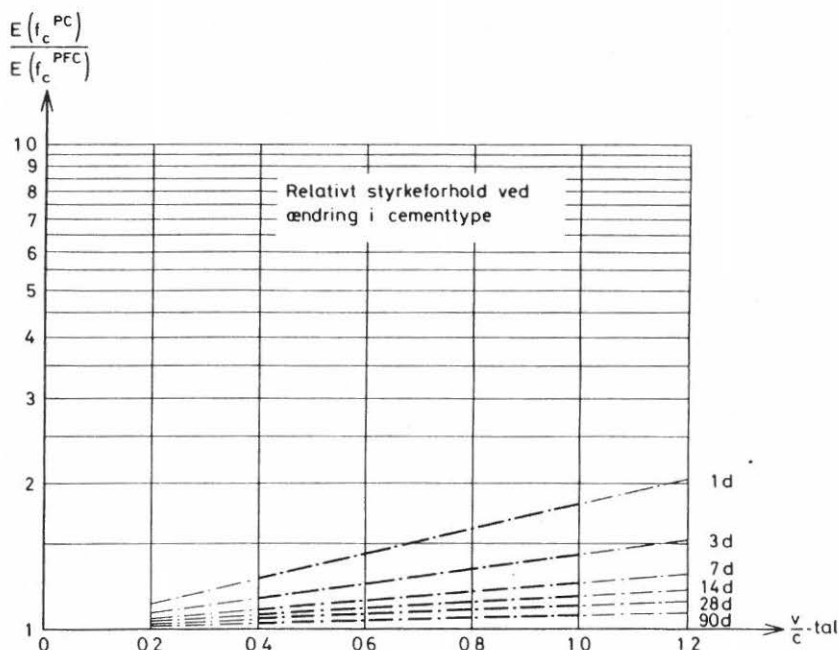
Denne formel er afbildet i figur 6.

Ændret $\frac{V}{C}$ -forhold

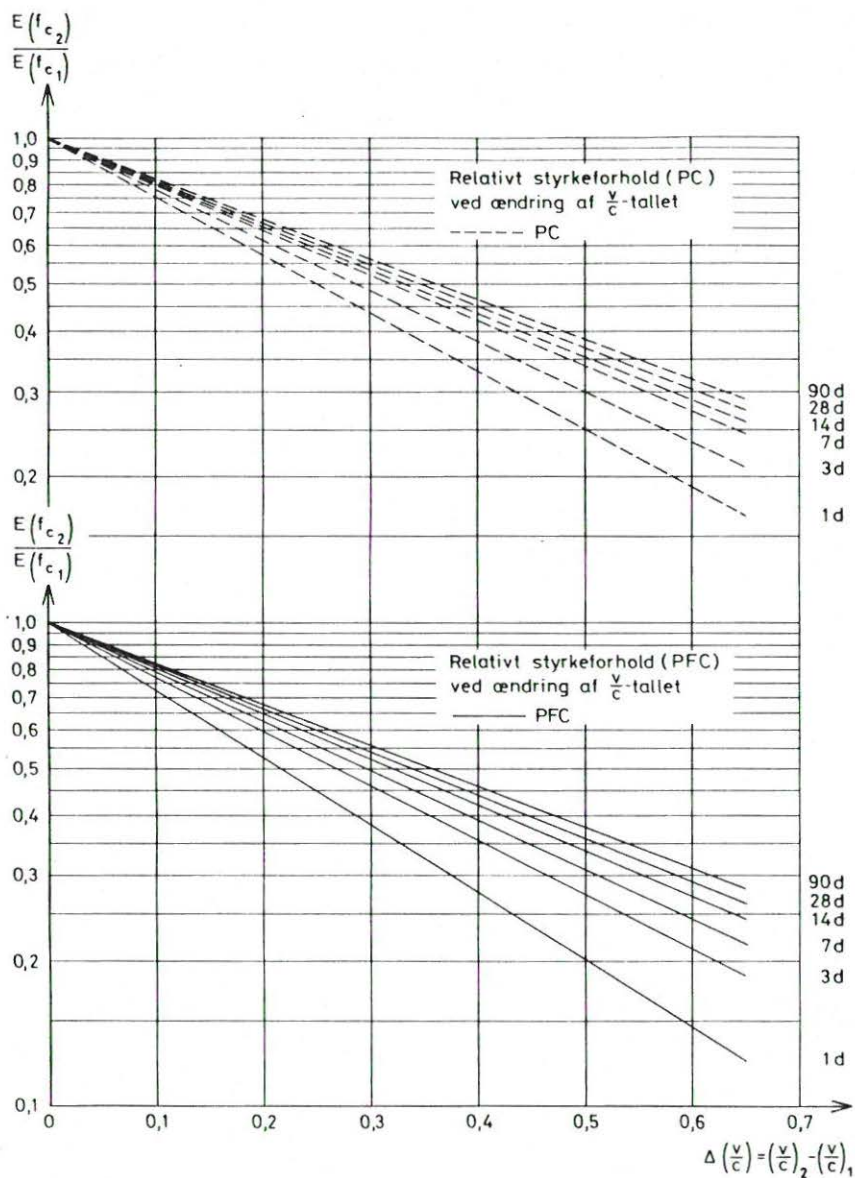
Hvis man har lavet sin beton med et andet $\frac{V}{C}$ -tal end antaget, vil styrkeforholdet til samme tidspunkt t være givet ved

$$\ln \frac{E(f_{c2})}{E(f_{c1})} = ((\frac{V}{C})_2 - (\frac{V}{C})_1) (A_2 + \frac{A_3}{\sqrt{t}}) \quad (5)$$

Denne formel er afbildet i figur 7, øverst for PC, nederst for PFC.



Figur 6. Ændret cementtype.



Figur 7. Ændret $\frac{V}{C}$ -forhold.

EKSEMPLER

En beton er fremstillet med $\frac{V}{C} = 0,6$ og PFC.

Hvor stor er styrken efter 1 døgn og 7 døgn?

Figur 1 giver $E(f_{c1}^{PFC}) = 9 \text{ MN} \cdot \text{m}^{-2}$

og $E(f_{c7}^{PFC}) = 23 \text{ MN} \cdot \text{m}^{-2}$

Det relative styrkeforhold er da 2,56, hvilket kan aflæses af figur 2, som også giver 28 døgns styrken = 32 MN · m⁻².

Hvis man har anvendt PC i stedet for, er styrkeforholdet til $t = 1, 7$ og 28 døgn henholdsvis 1,42, 1,14 og 1,07 (figur 6). Det betyder, at

$$E(f_{c1}^{PC}) = 1,42 \cdot 9 = \underline{13 \text{ MN} \cdot \text{m}^{-2}}$$

$$E(f_{c7}^{PC}) = 1,14 \cdot 23 = \underline{26 \text{ MN} \cdot \text{m}^{-2}}$$

$$E(f_{c28}^{PC}) = 1,07 \cdot 32 = \underline{34 \text{ MN} \cdot \text{m}^{-2}}$$

Er betonen fremstillet med et højere $\frac{V}{C}$ -tal end forudsat, bliver styrken mindre. Ved en differens på 0,1 vil styrkeforholdet ved 1, 7 og 28 døgn være 0,72, 0,79 og 0,83 (PFC, figur 7).

Der kan derfor forventes følgende styrker

$$E(f_{c1}^{PFC}) = 0,72 \cdot 9 \sim \underline{6,5 \text{ MN} \cdot \text{m}^{-2}}$$

$$E(f_{c7}^{PFC}) = 0,79 \cdot 23 \sim \underline{18,0 \text{ MN} \cdot \text{m}^{-2}}$$

$$E(f_{c28}^{PFC}) = 0,83 \cdot 32 \sim \underline{26,5 \text{ MN} \cdot \text{m}^{-2}}$$

SYMBOLLISTE

A_1 til A_4 : Konstanter i Neppers formel (tabel 1)

$E(f_c)$: Betonens middeltrykstyrke i MN/m^2 , normalt efter 28 døgn ved 20°C

H : Hærtningshastighed

K : Konstant i Bolomeys formel, især afhængig af cementtype og lagringstid

PFC : Portland flyveaskecement, som er almindelig hærtnende

PC : Rapidcement, som er hurtighærtnende

t : Modenhed ved 20°C

$\frac{V}{C}$: Forholdet mellem vandmængde i l og cementmængde i kg

LITTERATUR

Betonbogen
Aalborg Portland, 2. udgave 1985
ISBN 87-980916-0-8

the 1990s, the number of people in the UK who are employed in the public sector has increased by 1.5 million, from 2.5 million in 1980 to 4 million in 1995. The public sector has become a major employer in the UK, and its growth has been a key factor in the overall growth of the economy.

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